A DESCRIPTION OF THE SALINITY REGIMES OF MAJOR SOUTH CAROLINA ESTUARIES[1]

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INTRODUCTION

South Carolina has a wide variety of coastal river systems, which include extensive systems with a large freshwater discharge (> 250 m^3/sec), e.g. the Santee and Pee Dee Rivers, and coastal systems of minimal discharge (< 10 m^3/sec), e.g. the Stono, Ashley, and Wando Rivers (Fig. 1). These estuaries are important not only for their freshwater discharge, but also for their finfish and shellfish populations and for their scenic and recreational value.

Most of the hydrographic estuarine studies in South Carolina have been of short duration and geographically limited. Such studies, though valuable, often provide only limited information on estuarine salinity regimes and are utilized mainly to illustrate the results of low flow (U .S. Environmental Protection Agency 1974; Shealy and Bishop 1979), moderate flow (Kjerfve and Greer 1978), high flow (Burrell 1977), or environmental surveys (Battle 1890; Cummings 1970; Stephens et al. 1975).

The goal of this study was to determine spatial and temporal salinity trends in major South Carolina estuaries on a long-term basis. Unfortunately, little work of this type was done prior to the 1942 diversion of much of the Santee River flow into the Cooper River via Lakes Marion and Moultrie. Zetler (1953) measured salinity in Charleston Harbor prior to and after diversion of the Santee River, but no corresponding work was performed in the Santee River. The results of our study in conjunction with the work of others will provide a good data base with respect to future environmental modifications of major proportions, such as the rediversion of about 85% of the Santee River flow back to its original bed. The rediversion, scheduled for completion in 1983, will essentially re-establish the prediversion salinity conditions in the Santee. For additional information on the Santee River modifications refer to Kjerfve (1976). The Cooper River and Charleston Harbor will receive far less fresh water after rediversion than before, i.e. 85 m^3/sec vs 450-550 m^3/sec, but much more than the prediversion discharge of < 6 m^3/sec.

SAMPLING DESIGN AND METHODS

Salinity samples were collected monthly at stations in several South Carolina estuaries (Fig. 1). Studies were conducted on the North and South Edisto Rivers during 1973-74, the North and South Santee Rivers during 1975-76, Winyah Bay and its tributaries during 1977-78, and the Cooper River-Charleston Harbor system from 1973 to 1977.

Stations were chosen to identify present salinity regimes and extended from marine to freshwater environments. Consideration in the choice of station locations was also given to future development or environmental modification that might affect river discharge.

All samples were collected on the early flood tide with a 6-liter Van Dorn bottle at 1 m below the surface and 0.3 m above the bottom (augmented with a bottom tripping assembly). No bottom samples were collected at South Edisto stations D001 and D003 due to the shallowness ($\leq$ 4.0 m) of the river at those locations. Samples were placed in 250 ml polyethylene bottles for laboratory analysis. All analyses were performed on a Beckman RS7B induction salinometer.

RESULTS AND DISCUSSION

The following results represent inter- and intra-estuarine comparisons, with special emphasis being given to intra-estuarine relationships. Relationships between salinity, rainfall, and river discharge were considered in an effort to delineate recognizable trends. An interpretational problem arose due to the time lag between rainfall across the state and river discharge. As a result of this time lag and the consequent potential for misinterpretation, no comparisons were made between precipitation in the watershed and corresponding downstream salinity changes.

The Edisto River

The first estuary sampled during this study was the Edisto, which is basically an undisturbed blackwater river with minimal development along its entire length. The mean discharge recorded near Jacksonboro, S.C., was 76.2 m^3/sec (U.S. Geological Survey 1976). The North and South Edisto distributaries comprise the estuarine portions of the river, with the North Edisto receiving only a small portion of the freshwater discharge.

The permanent freshwater line ($\leq$ 0.5 ppt) in the South Edisto was found about 35 km upstream or 3-4 km below station D001. This appears to be a realistic estimate of the location of the permanent freshwater line, since the precipitation extremes encountered during this study scarcely affected the salinity at station

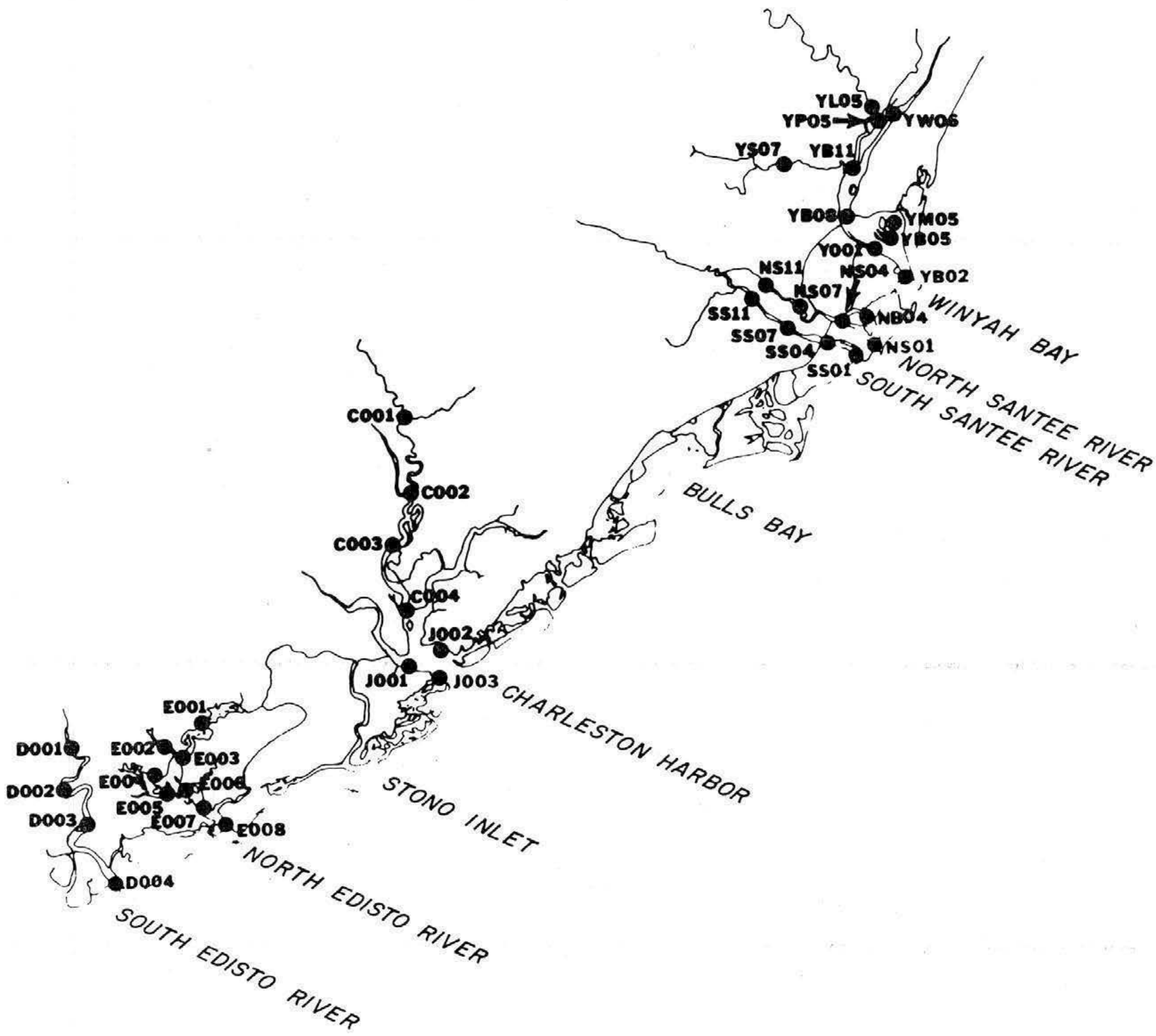

Fig. 1. Stations sampled monthly in estuaries along the coast of South Carolina.

D001, i.e. salinity ranged from 0.0 to 1.5 ppt with a mean of 0.2 ppt. In contrast, the North Edisto had no permanent freshwater line, the only major estuary in this study without one (Fig. 2).

Stratification was generally quite low, whether considering monthly or mean salinities. Using time-averaged values, the mean vertical salinity gradient was 0.15 ppt/m at station D004 and 0.11 ppt/m at D002 in the South Edisto. Stratification in the North Edisto was also low, being 0.13 ppt/m at E006 and 0.24 at E008. The greatest stratification occurred at station E004 where the mean vertical salinity gradient was 0.35 ppt/m. This may be due to the freshwater input of the South Edisto at the surface via the Dawho River (Fig. 2).

The surface horizontal salinity gradient between South Edisto stations D004 and D003 was found to be about 1.1 ppt/km for the distance of 14 km. No bottom calculations were performed due to the shallowness of stations D001 and D003 and the consequent absence of data. In the North Edisto the surface horizontal salinity gradient between stations E008 and E006 was 0.29 ppt/km, while the bottom horizontal gradient was 0.36 ppt/km.

A comparison of Edisto River discharge and salinity (Fig. 3) at the respective sampling stations illustrates several instances of reduced river discharge and reduced salinity, e.g. September 1973 at stations D002-D004 and January 1974 at D002 and D003. These salinity changes are probably the result of tidal action and are consequently episodic and perhaps of limited importance.

The Santee River

The North and South Santee distributaries are quite similar in salinity distribution (Fig. 4), which is rather surprising in view of differences in flow, i.e. 85% in the North Santee and 15% in the South Santee (Cummings 1972) or 73% to 27%, North to South (Kjerfve and Greer 1978). Our data indicate that both estuaries were essentially fresh about 18-19 km from the mouth. Nelson (1976) found similar results during 1974-1975, with the permanent freshwater line located about 19-23 km from the mouth in both estuaries. Kjerfve and Greer (1978) found freshwater about 7-8 km upstream during a period of moderate discharge (316 m^3/sec) and noted that the salinity distribution was basically the same in both estuaries. During the great spring freshet of 1975, Burrell (1977) reported fresh water at the mouths of both distributaries. Nelson (1976) found somewhat higher salinities in the South Santee than in the North Santee, but each estuary was fresh about 18-21 km from the river mouths, with the annual discharge varying from normal ($\sim$ 14 m^3/sec) to high ($\sim$ 450 m^3/sec).

North Santee Bay, a large, shallow bay near the mouth of the North Santee River, was sampled at station NB04 (Fig. 1) during 1975-76. Salinities were generally higher at NB04 than at NS04, with values being up to 20 ppt higher at NB04. Since North Santee Bay essentially connects the Atlantic Intracoastal Waterway (AIWW) with the ocean via the mouth of the North Santee River, the bay may serve as a path for transporting high salinity water northward to Winyah Bay.

Stratification in the lower Santee was generally weak, i.e. mean vertical salinity gradients were 0.38 ppt/m for station SS01, 0.51 ppt/m for NS01, and 0.20 ppt/m for NS04. Kjerfve and Greer (1978) found a similar vertical salinity gradient (0.4 ppt/m). Our data, however, indicated a vertical salinity gradient at SS04 of 1.28 ppt/m, possibly the result of transport of higher salinity bottom water via the AIWW (Fig. 1).

The North Santee horizontal salinity gradient, surface and bottom, was about 2.9 ppt/km for the NS01-NS04 segment. The South Santee surface salinity gradient was 2.4 ppt/km for the SS01-SS04 segment, while the bottom gradient was 1.8 ppt/km.

As in the case of the South Edisto River, some seemingly anomalous trends in salinity were detected in the North and South Santee distributaries. Salinity rose at all stations except NS07 during May and July 1975 during moderately high discharge (> 120 m^3/sec) (Fig. 5). Also the salinity dropped sharply in July 1976 during an extended period of low discharge ($\sim$ 14.2 m^3/sec).

Winyah Bay

Winyah Bay receives total river discharge comparable to that of the Cooper River (> 450 m^3/sec) (U.S. Geological Survey, 1979) from the Pee Dee, Little Pee Dee, Waccamaw, Black, Lynches, and Sampit Rivers (Fig. 1). Despite the large river discharge and the relative significance this may imply with respect to other South Carolina estuaries, little hydrographic work has been performed in Winyah Bay, one exception being the study by Johnson (1972) from December 1969 through May 1971.

Our data indicated that fresh water ($\leq$ 0.5 ppt) was found 31 to 33 km upstream in the Pee Dee and Waccamaw Rivers, which corresponds roughly to the location of freshwater in the South Edisto. Based solely on river discharge (> 450 m^3/sec for Winyah Bay and $\sim$ 76 m^3/sec for the South Edisto River), an unlikely situation would exist. The reason, however, for the similarity in locations of the

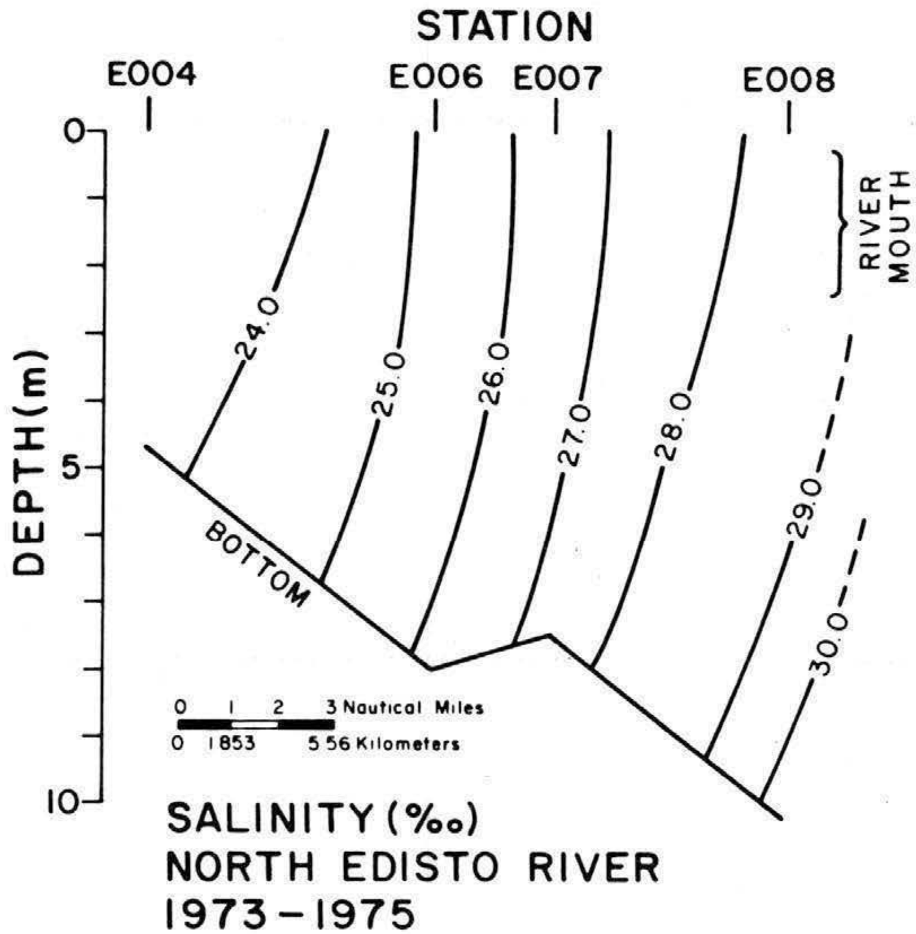

Fig. 2. Isohalines for North Edisto River stations, based on mean surface and bottom salinities.

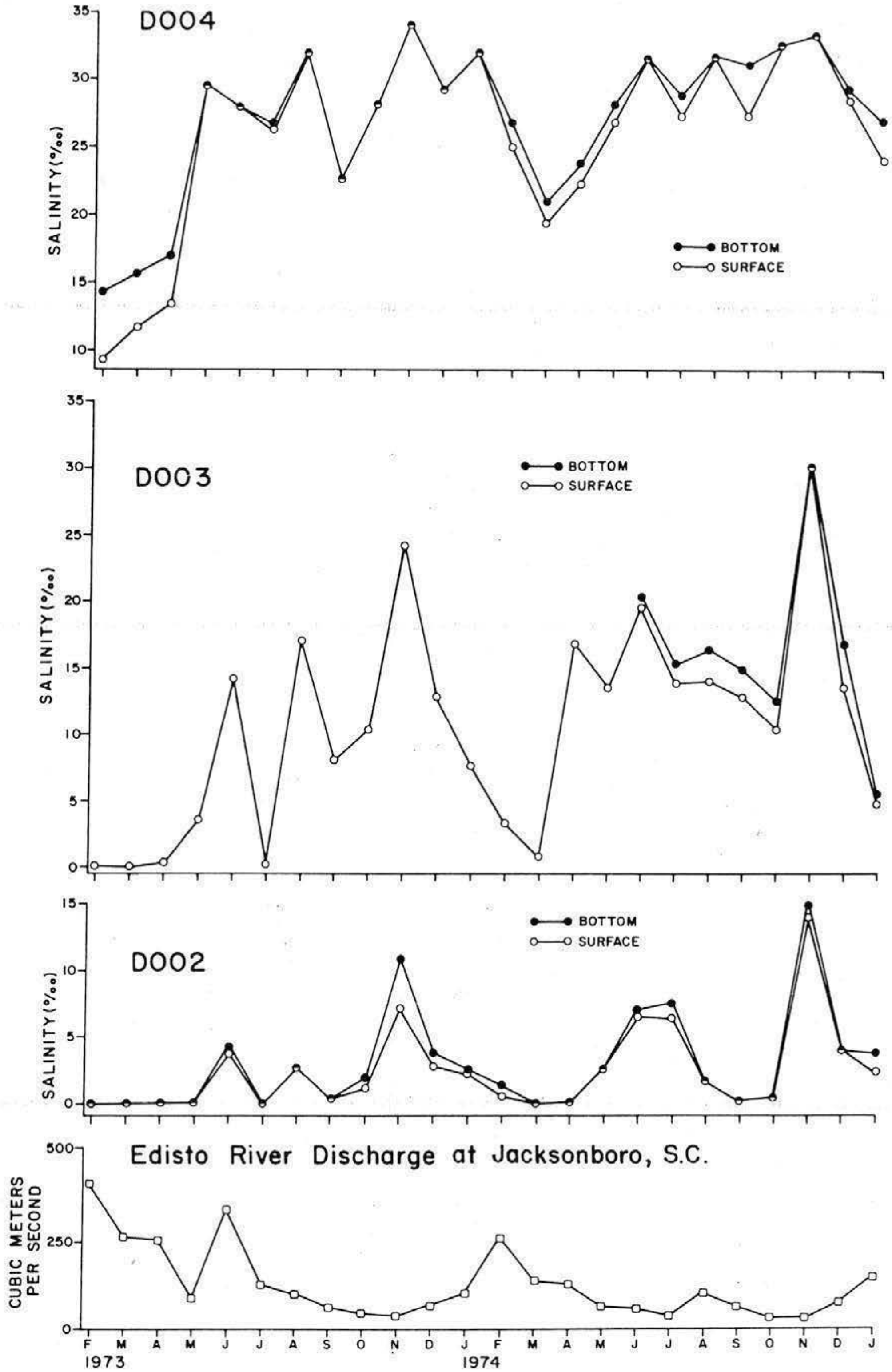

Fig. 3. Surface and bottom salinity at selected Edisto River stations and Edisto River discharge (U. S. Geological Survey 1974, 1975, 1976).

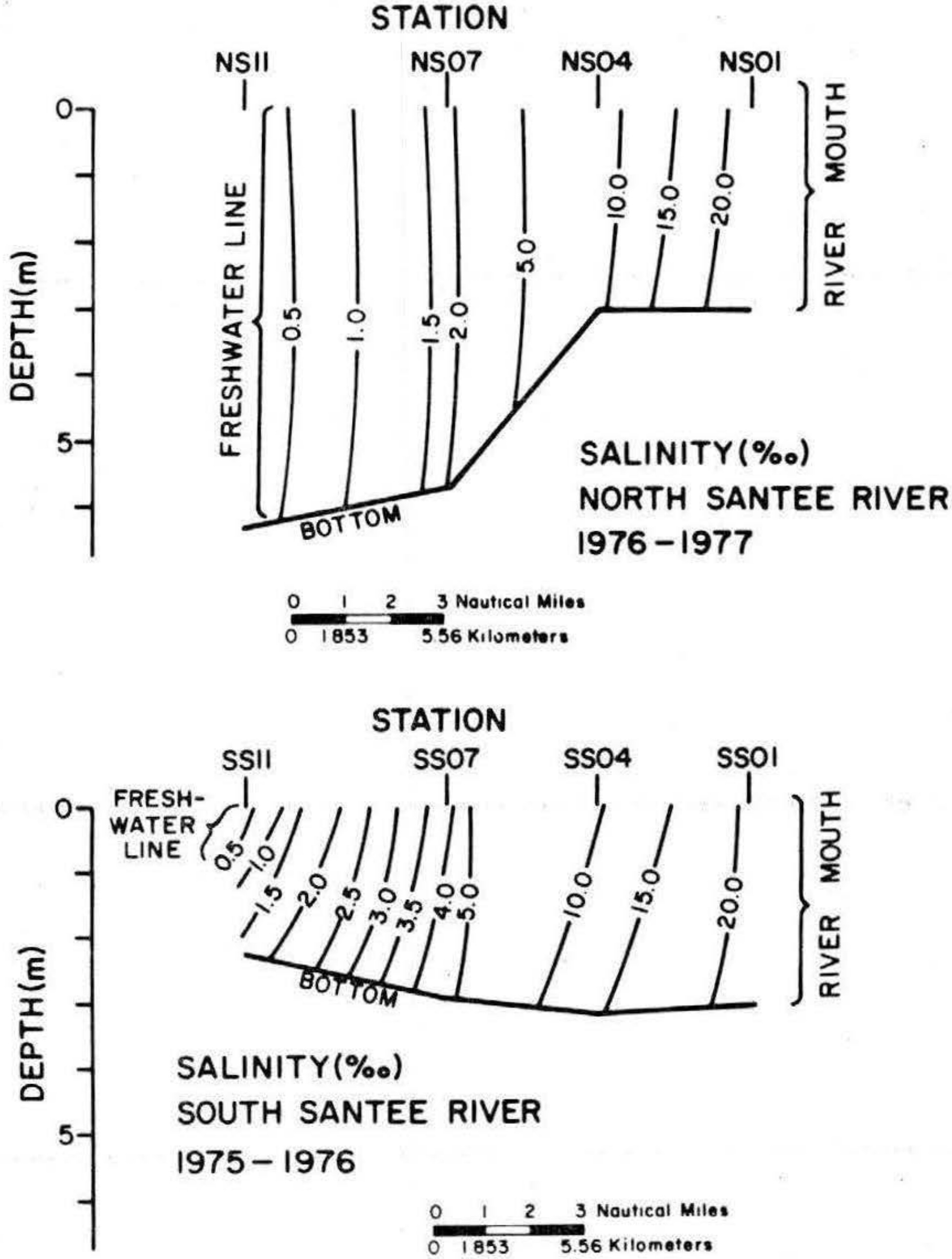

Fig. 4. Isohalines for North and South Santee River stations, based on mean surface and bottom salinities.

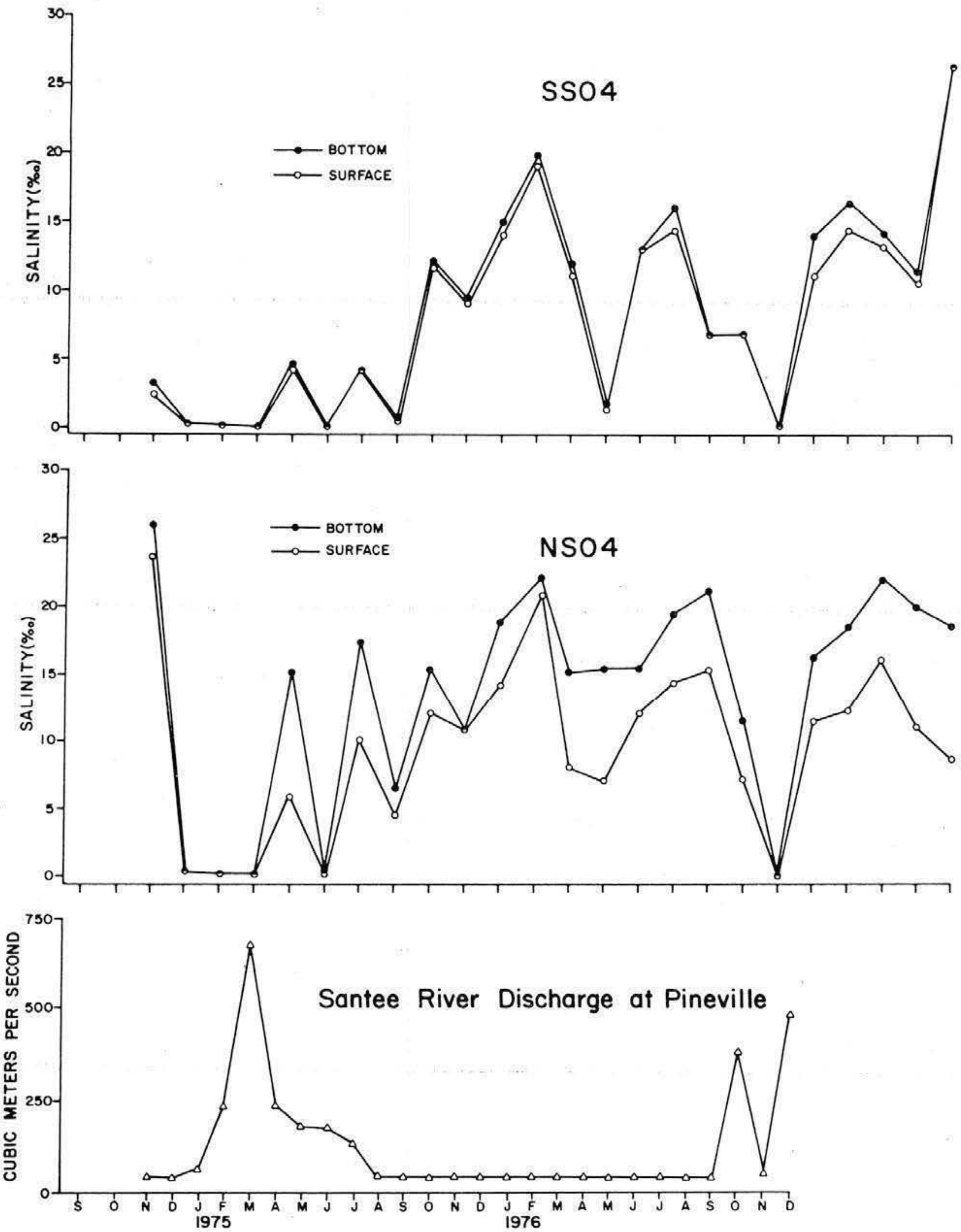

Fig. 5. Surface and bottom salinity at North and South Santee River stations and Santee River discharge (U. S. Geological Survey 1976, 1977, 1978).

freshwater lines is undoubtedly related to the depth, width, orientation, and presence or absence of a bay at the mouth of each estuary (Pritchard 1954, 1967). Johnson (1972) found that the freshwater line in Winyah Bay extended from 22.5 km to 48 km upstream, with the average location being about 37 km above the mouth of Winyah Bay.

Stratification in Winyah Bay is relatively high due to the amount of freshwater discharge. The vertical salinity gradients at stations YB02, YB05, and YB08 were 0.78 ppt/m, 0.90 ppt/m, and 0.64 ppt/m respectively (Fig. 6).

The horizonal salinity gradient in Winyah Bay was not as strongly developed as that of the South Edisto River, i.e. 0.96 ppt/km from YB02 to YB05 or 1.01 ppt/km from YB02 to YB08 as compared with 1.4 ppt/km in the South Edisto.

Several apparently anomalous salinity distributions were noticeable, e.g. bottom salinity during October and December 1977 was higher at YB05 than at YB02 (Fig. 7). The same situation existed during November 1977 when the bottom salinity was higher at YB08 than at YB05 (Fig. 7). The bottom salinity was also greater at YB11 than YB08 during July 1977 and March, July, and August 1978 (Fig. 7).

Charleston Harbor-Cooper River Estuary

Of the major estuarine systems in South Carolina, the Charleston Harbor-Cooper River Estuary has been altered more by man's activities due to the 1942 Santee River diversion and the high level of industrialization located at its mouth. However, until this study, Charleston Harbor-Cooper River was the subject of short-term studies, e.g. U.S. Environmental Protection Agency (1974) and Shealy and Bishop (1979). Our study, however, was conducted from February 1973 through December 1977 at stations from the mouth of Charleston Harbor to the "Tee", the junction of the East and West Cooper branches (Fig. 1).

In this study we have treated Charleston Harbor and the Cooper River together since they are physically part of the same estuarine system. Previous studies have dealt with the Cooper River alone and defined the mouth of the river at various locations between C004 and J003. Using our approach, the freshwater line is located about 39-41 km from station J003 or about 6 km upstream of station C002 (Fig. 8).

In terms of mean vertical salinity gradients, the Charleston Harbor-Cooper River system has the strongest gradients except for the South Santee station SS04. The gradient at station J003 is 0.87 ppt/m compared to 1.28 ppt/m at SS04. The J003 gradient roughly equals that of Winyah Bay station YB05, i.e. 0.90 ppt/km.

Horizontal salinity gradients in Charleston Harbor-Cooper River were not especially strong in comparison to the other estuaries in this study. The mean surface horizontal gradient was 1.1 ppt/km, while the bottom was 1.3 ppt/km for the J003-C004 segment. These values are slightly higher than those for Winyah Bay, but lower than in the other estuaries.

Many salinities were recorded that were seemingly in disagreement with river discharge data. Only a few of the possible examples will be mentioned here, such as the increase in bottom salinity during January 1976 and 1977 at station C004 during a period of high discharge (Fig. 18). Other examples occurred when the bottom salinity rose at station J001 during January and February 1976 and December 1976 to January 1977 when river discharge was high (Fig. 9).

SUMMARY AND CONCLUSIONS

This study has provided a long-term description of salinity regimes in major South Carolina estuaries. Salinities were found to range from 0.5 $^{o}/oo$ to about 35 $^{o}/oo$, depending on varying factors such as river discharge, climatic conditions, and tidal action. A permanent freshwater line was defined for each estuary in this study with the exception of the North Edisto River, which had a minimal freshwater input. The location of freshwater extended from about 18-19 km upstream in the North and South Santee system to approximately 39-41 km upstream in the Cooper River.

Some apparent anomalies were detected in which salinity in several instances did not correspond to river discharge. In some instances salinities rose when river discharge was high, while the opposite situation existed during periods of low river discharge, due undoubtedly to tidal fluctuations.

The AIWW probably modified salinities in Winyah Bay and the South Santee River. One example was evident in Winyah Bay, where some upstream stations had higher salinities than their seaward counterparts. While the same situation was not detected in the South Santee, station SS04 had a relatively large vertical salinity gradient, possibly due to the introduction of high salinity water via the AIWW.

The salinity regimes in the various estuaries did not follow river discharge

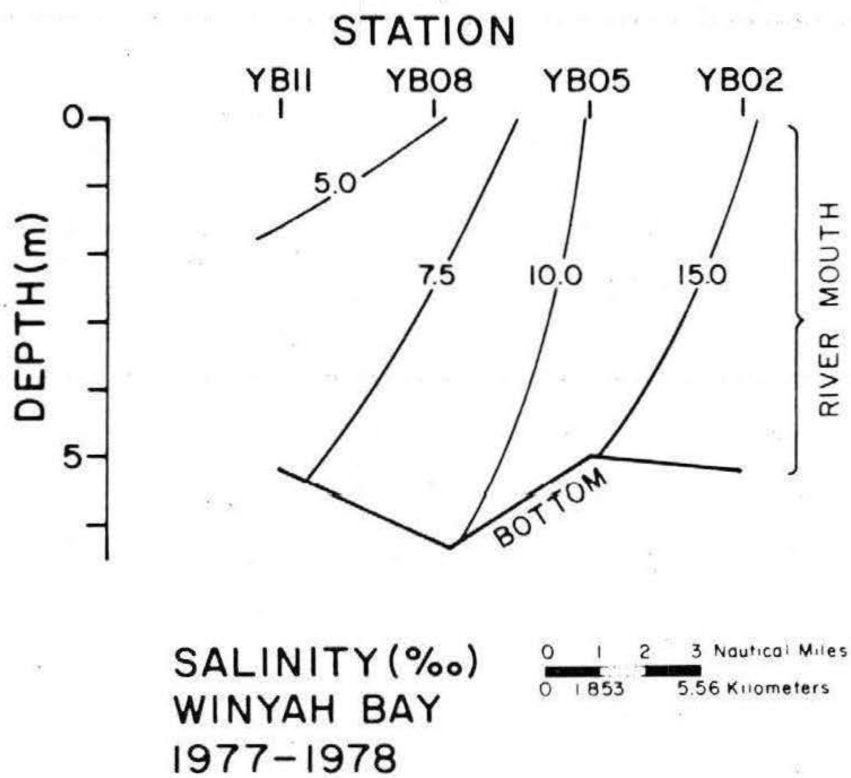

Fig. 6. Isohalines for Winyah Bay stations, based on mean surface and bottom salinities.

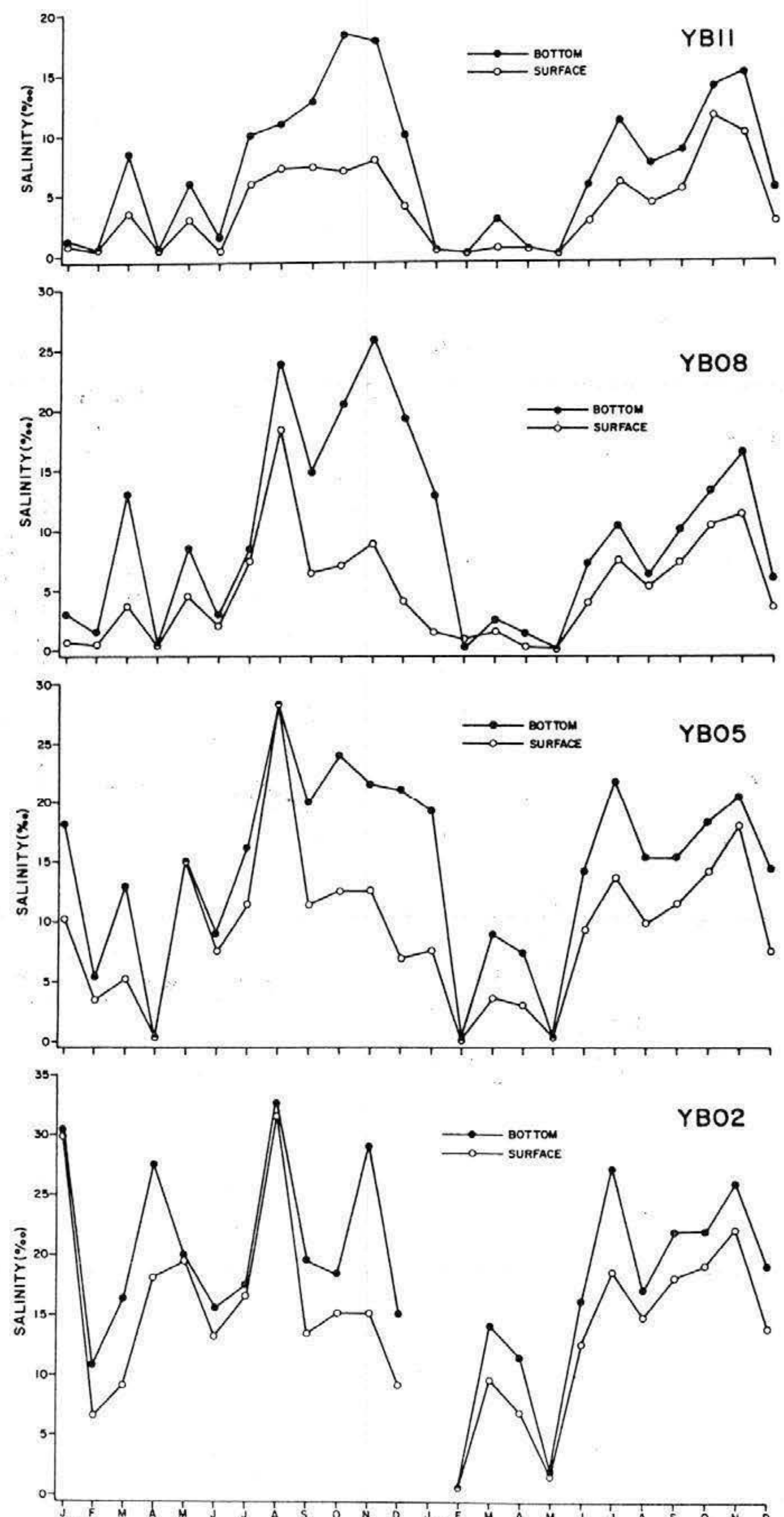

Fig. 7. Surface and bottom salinity for Winyah Bay stations.

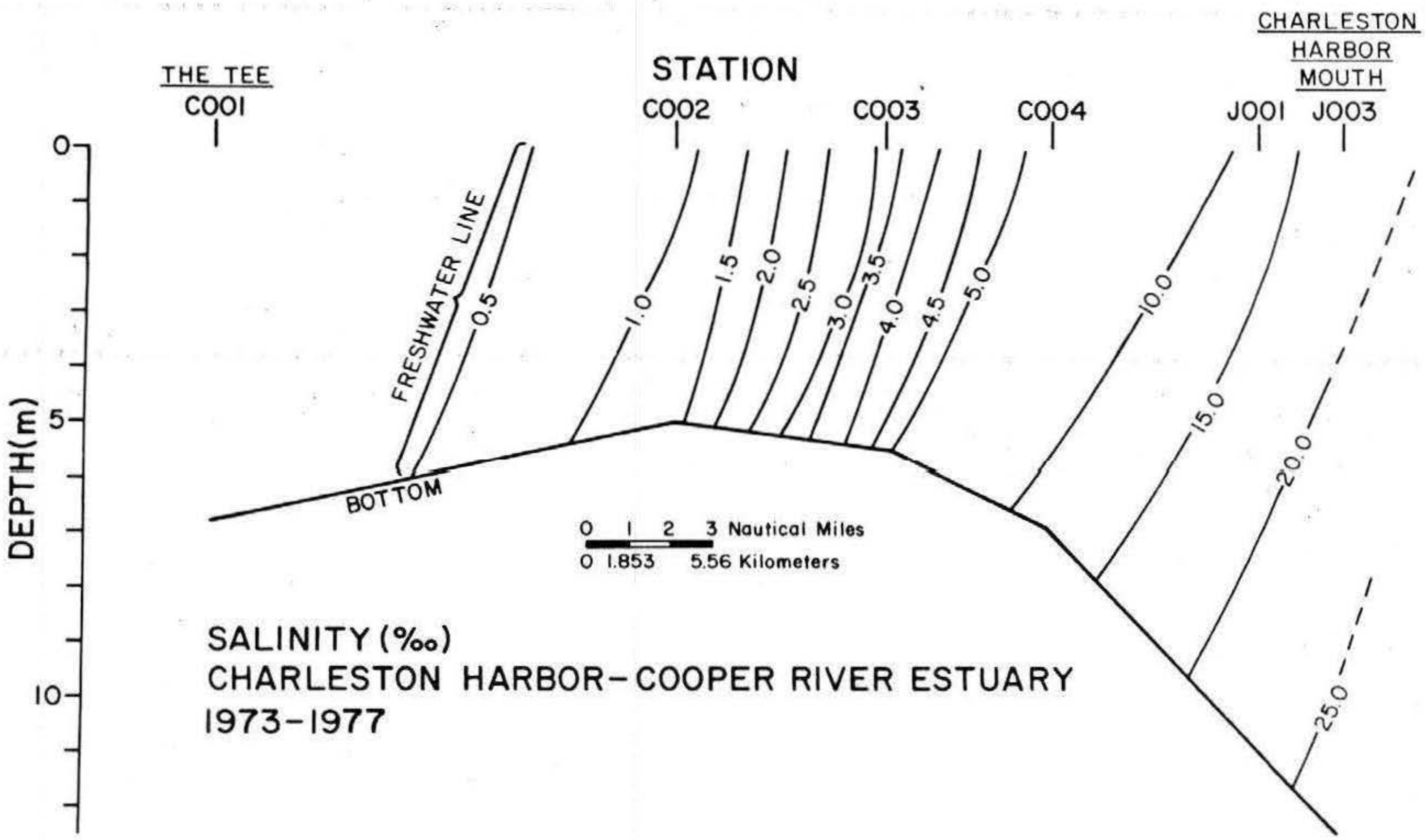

Fig. 8. Isohalines for Charleston Harbor-Cooper River stations, based on mean surface and bottom salinities.

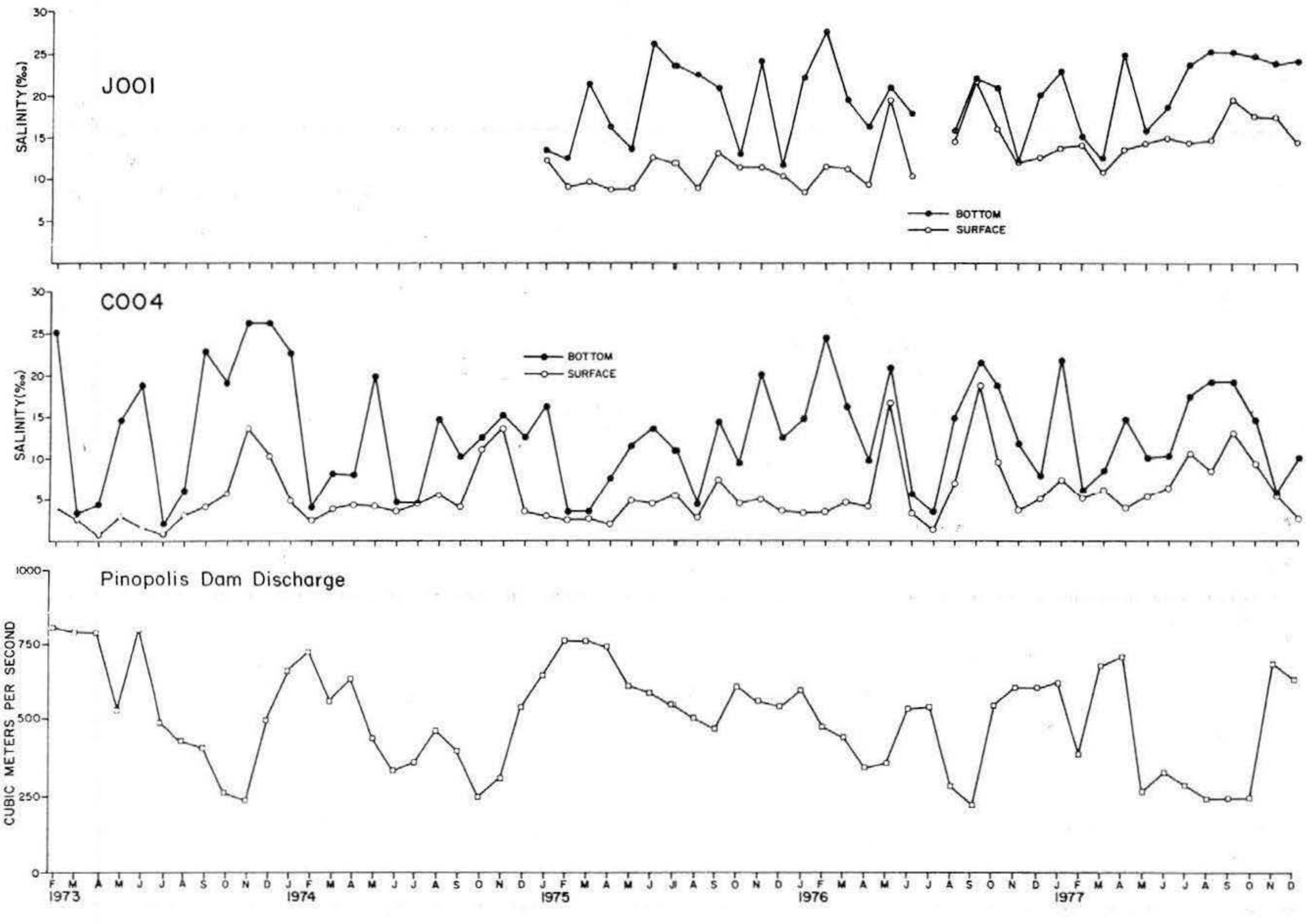

Fig. 9. Surface and bottom salinity for Charleston Harbor-Cooper River stations and Cooper River discharge (R. Leisure, S. C. Public Service Authority, pers. commun.).

very closely, which was particularly well supported by the locations of the permanent freshwater lines. The North and South Santee distributaries were fresh at about the same distance upstream (18-19 km) yet the North Santee had at least twice the freshwater flow. Also the Santee system with its low discharge had freshwater closest to the river mouths of any estuary in the study. This is probably a function of the width of the river mouths, the presence of bays, depth of the main channel, slope of the sides, and other factors. The North and South Santee Rivers have rather narrow mouths without deep bays in sharp contrast to Winyah Bay and Charleston Harbor. Hence vertical mixing is somewhat higher in the Santee estuaries, but the tidal influence may be less.

In conclusion, South Carolina estuarine systems are quite complex and subject to extremely large variations as a result of numerous influences. Salinity regimes in the major estuaries are not necessarily related to discharge, hence emphasizing the need to undertake large scale environmental modifications with the greatest of caution. The Santee-Cooper rediversion currently underway may in fact achieve its main goal of reducing dredging requirements in Charleston Harbor, but it may also produce changes in the present salinity regime beyond initial estimates, leading to uncertain consequences.

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